Effervescent Spray Characterization of Jatropha Pure Plant Oil

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Abstract

Spray structure of Jatropha curcas pure plant oil from an effervescent atomizer has been studied at different gas-to-liquid ratios (GLR) and pressures using nitrogen as atomizing gas. Shadowgraphy technique has been used to study both spray structure and droplet size measurements. The complete spray has been characterised from the exit orifice up to 95 mm downstream. From the shadowgraphy images of the complete spray indicates two modes of effervescent injector operation. At low pressure and low GLR, the spray was observed to intermittently display a finely atomized structure and a poorly atomized structure with an intact liquid core. Increase in the pressure or GLR beyond a certain value is observed to drastically reduce this intermittency. However, some unsteadiness in the spray structure still persists. Droplet size measurements were made in a 4 mm X 3 mm region 80 mm from the exit orifice. For the conditions studied, Sauter Mean Diameter in this region was found to vary from 40 to 60 μm.

Introduction

Due to depleting fossil fuel reserves and the impact of emissions on the environment, the use of biofuels such as plant/vegetable oils has been increasing in recent times. Since the physical properties of these fuels are different from those of conventional fuels, existing injection systems may not be effective and efficient. Specifically, with respect to pure plant oils (PPOs), the higher viscosity and surface tension compared to those of conventional fuels, lead to poor atomization.

Effervescent atomization is a method of twin fluid atomization developed by Lefebvre and co-workers [1-3] in late 1980s. In this method, a small amount of gas is injected into the liquid before the exit orifice to form a bubbly mixture of gas and liquid. On emerging from the nozzle, due to the pressure difference, gas bubbles rapidly expand and shatter the liquid into fine droplets. Hence, this method offers the advantage of smaller drop sizes at low injection pressures [1]. Due to these advantages, it has a potential application in gas turbines and internal combustion engines [4]. It was observed in the previous studies that effervescent injector spray characteristics depends on number of parameter and the important parameters are Gas to Liquid Ratio (GLR) , injection pressure, liquid properties and atomizer internal geometry. In the present study, spray is characterised by changing GLR and injection pressure. All the previous studies indicate that the flow regime (bubbly flow, slug and annular flow) inside the atomizer has a major effect on the spray structure. From experiments on a diesel substitute, Sovani [7] has identified four modes of injector operation. The first mode is spray-and-unbroken liquid jet mode, in which, at times unbroken liquid jet is observed instead of an atomized spray. The second is the highly pulsating spray mode in which cone angle fluctuations are quite large. The third mode corresponds to a slightly pulsating mode characterized by small cone angle variations and the last is the steady spray mode. From the internal flow observations, it was concluded that injector operates in the slug flow regime during the pulsating modes.

Most of the studies on effervescent injection studies in the literature are concerned with low viscosity liquids like water [1-4]. Buckner et al. [5] had conducted focused studies on very high viscosity liquids and concluded that effervescent atomization is one of the potential techniques for atomization of high viscosity liquids. There was no data available in the literature on effervescent atomization of pure plant oils. This is the first study to the best of our knowledge, wherein detailed characterisation of an effervescent spray of Jatropha oil is reported.

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Materials and Methods

The Effervescent atomizer used in this study is shown in Fig 1a. The design of the atomizer is similar to the one used in the study by Sher et al. [6]. Liquid and gas are introduced in to the atomizer through different paths. Liquid enters into the concentric tube from the top and gas inters into the surrounding chamber from side passage. A centrally located tube of 4.5 mm internal diameter is provided with 20 holes each of diameter 200 µm. Atomizing gas enters the liquid through the 200-micron holes in the central tube and forms two phase mixture. The resulting two-phase mixture flows through the tube and exits through a 0.8 mm diameter single hole. Since the gas enters into the liquid from annular chamber, it is referred to as an "outside-in" type atomizer.

The gas and liquid supply system is shown in Fig 1b. Liquid to be sprayed is stored in reservoir and is pressurised with the gas through surface contact. The pressurised liquid from the reservoir flows through a pressure regulator and a needle valve is used to control the liquid flow rate. A gear flow meter (Flowtechnik model GFM 3143-02-S-35.00) in the line measures the flow rate of the liquid. Temperature and pressure gages are incorporated in the line to measure injection temperature and pressure respectively. The atomizing gas from the bottle passes trough the pressure regulator into gas supply line. The thermal mass flow controller (Brooks model SLA5850S) controls the amount of gas to be injected. Similar temperature and pressure measurements are also conducted in the gas line.

Instrumentation used in this study includes a pulsed Nd:YAG laser which is used as a light source, a fluorescent diffuser to backlit the spray and an Imager Pro X 2M CCD camera with 1600 X 1200 pixel CCD resolution to capture images of the spray. Synchronisation and controlling of the instrumentation is done by DaVis software from LaVision Gmbh. Experimental data was collected using shadowgraphy-based backlighting technique. Two sets of experiments were carried out to characterize the spray. The first set involved obtaining a complete image from the exit orifice up to 95 mm downstream, mainly to visualize the overall structure of the spray. The second experiment involved obtaining droplet sizes in a 4 mm X 3 mm region, 80 mm downstream of the exit orifice. The technique is based on high resolution imaging with pulsed backlight illumination. A very short 7ns laser pulse is used to freeze the motion of the droplets. Images were taken at a rate of 10 frames/s. When capturing images for drop sizing, it is often likely that droplets not present in the focused plane are also captured. Out-of-focus droplets look larger than their actual size, and this needs to taken into account while calculating droplet size. Depth of field correction calibration using a calibration plate with 10-200 µm dots was done. A 20 % deviation in the diameter is set as an allowable value for considering out-of-focus droplets.

Results and Discussion

Experiments were carried out for Jatropha curcas oil using nitrogen gas as an atomizing gas. The experimentally determined properties of the Jatropha oil sample used are shown in Table 1. During the experiments, amount of the gas injection is varied by keeping the liquid flow constant. The liquid injection pressure was varied to keep the liquid flow rate constant at different gas flow rates. In this paper, liquid pressure is taken as injection pressure of the atomizer. For each case, Gas to Liquid Ratio (GLR) is calculated as the ratio of mass flow rate of the gas to the mass flow rate of the liquid.

Effervescent spray images were taken at different GLR and different injection pressures using backlight imaging. A total of 100 images were taken at the rate of 10 frames/sec to study the structure of the spray. Figure 2 shows six consecutive images taken at two different conditions. The first corresponds to GLR of 0.17 and 5 bar pressure and the second corresponds to GLR of 0.35 and a pressure of 9 bar. From the images, it appears that the conditions studied here correspond to the first two modes reported by Sovani [7]. Specifically, the spray corresponding to GLR of 0.17 can be classified as belonging to first mode, while the spray with GLR of 0.35 corresponds to the second mode. Similarly, modes are identified for all conditions studied here, and the results are shown in Fig 3. From this figure, it is observed that at low GLR and low pressure, spray structure corresponds to the first mode. Increasing the GLR or pressure is observed to shift the spray to the second mode. It is reported in the literature that spray pulsation occurs mostly when the atomizer operates in the slug flow regime [7]. This may be the reason for the first mode behaviour at low GLR. At high GLR, due to increased gas flow rates, the two-phase flow tends to move away from the slug flow regime. This may be the reason for improved atomization and second mode behaviour. Increasing the pressure will increase the energy in the atomizing gas and helps in better atomization. Thus, increase in pressure and GLR cause a shift from mode 1 to mode 2. Further increase in the pressure or GLR may result in transition to higher modes. This needs to be investigated further.

Droplet size Measurements:

Droplet size measurements of the effervescent spray were done using shadowgraphy imaging technique. Spray images were taken in a 4mm X 3mm region at a location, 80 mm downstream of the exit orifice. A total of 100 images were taken at 10 frames/sec to obtain statistically-averaged results. Experiments were carried out at liquid flow rate 1 ml/s to 5 ml/s in steps of 1 ml/s. At each liquid flow rate, gas flow rate was varied between 15 slpm, 30 slpm and 45 slpm. Pressure was varied and recorded to keep the liquid flow rate constant while the gas flow rate is changed. A typical image of the spray in the above-mentioned region is shown in Fig 4. It was observed that around 4 to 8 percent of the total images recorded showed the presence of ligaments; these images were not considered for droplet size measurements. Figure 5 shows a decrease in the SMD values as the GLR increases for all the liquid flow rates. Since higher GLR in the experiments corresponds to higher pressure, the energy carried by the atomizing gas is also higher and this results in smaller drop sizes. Since pressure is also varied at each liquid flow rate, data were grouped into different pressure ranges and presented in Fig 6. At lower pressure ranges, drop sizes increased with GLR initially and then decreased. This may be attributed to change in the flow regimes inside the atomizer. This aspect needs to be studied further.

Conclusions

Effervescent atomization of Jatropha curcas oil has been studied using nitrogen as atomizing gas. Spray images were taken at different liquid flow rates and GLRs. It was observed that the spray structure corresponds to the first mode at low pressure and low GLR, and in the second mode at high pressure and high GLRs. Droplet size measurements showed that for a given liquid flow rate, increase in the GLR reduces the SMD. Initial increase in the droplet size with GLR at low pressures is an interesting observation which needs to be further investigated.

Nomenclature

GLR	Gas to Liquid Ratio
SMD	Sauter Mean Diameter

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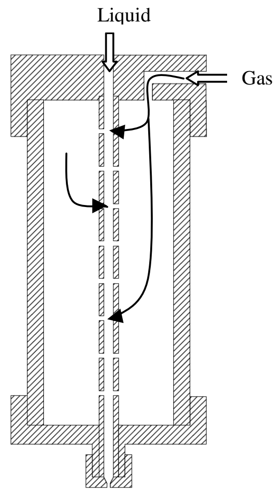


Figure 1 a. Schematic of effervescent atomizer used in this study

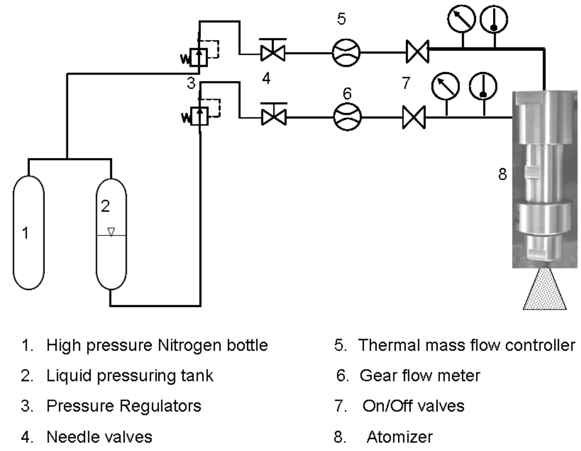
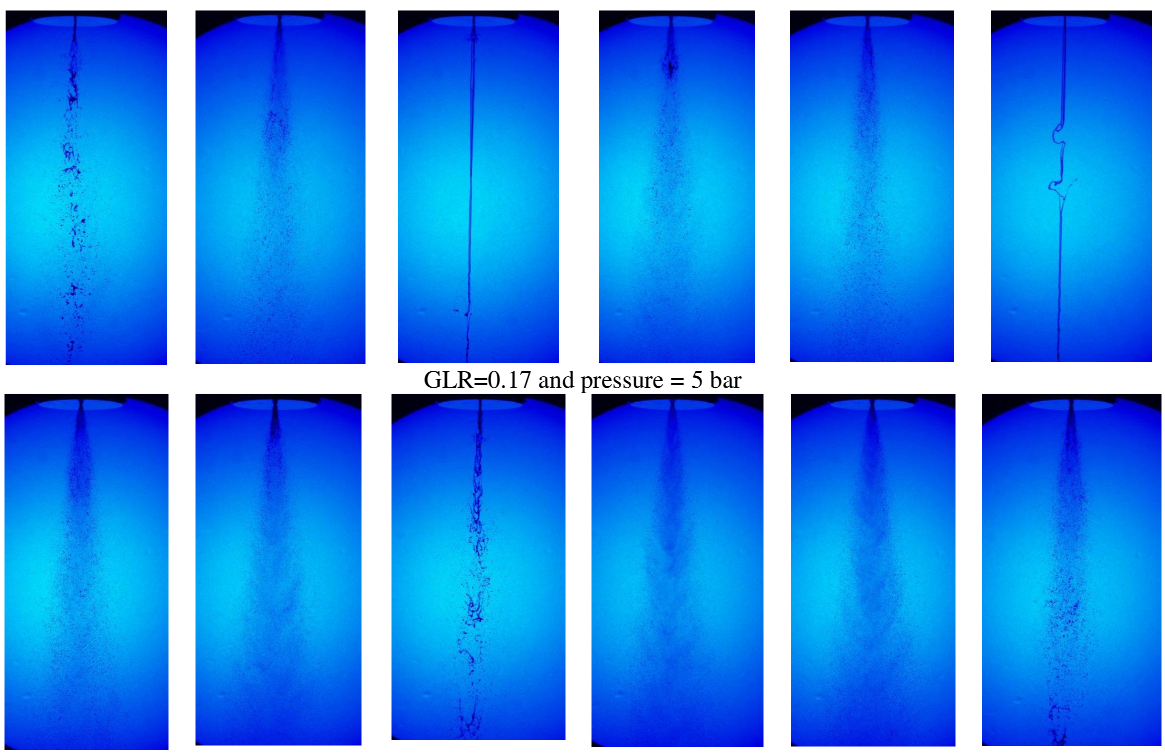


Figure 1 b. Schematic of the setup used in the present study



GLR=0.17 and pressure = 5 bar

GLR= 0.35 and pressure = 9 bar

Figure 2. Images of effervescent spray

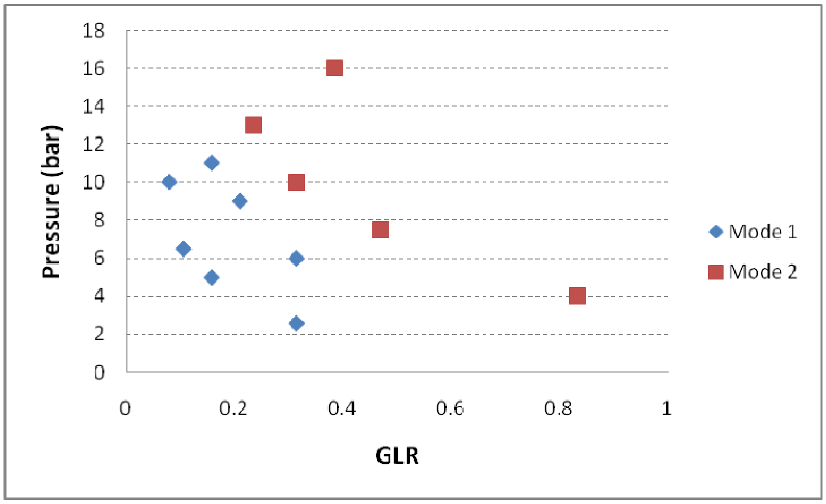


Figure 3. Modes of effervescent spray at different conditions

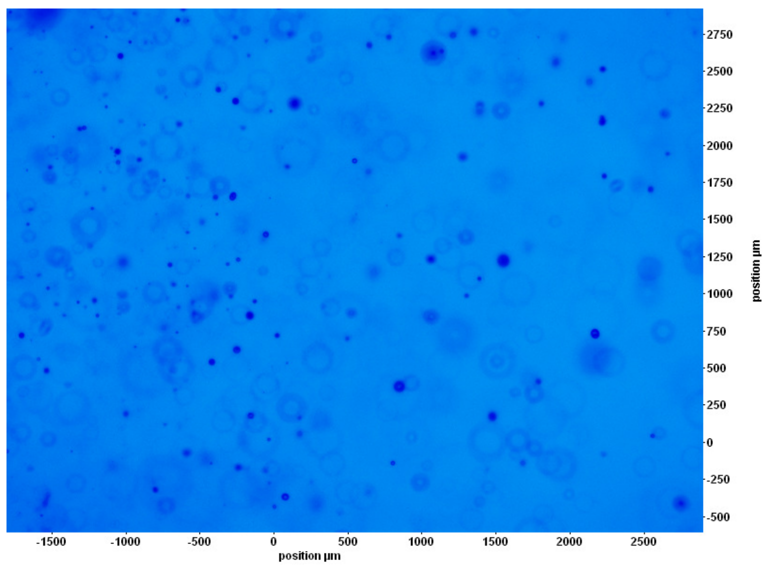


Figure 4. Typical shadowgraph image in a 4 mm X 3 mm region at 85 mm from exit orifice

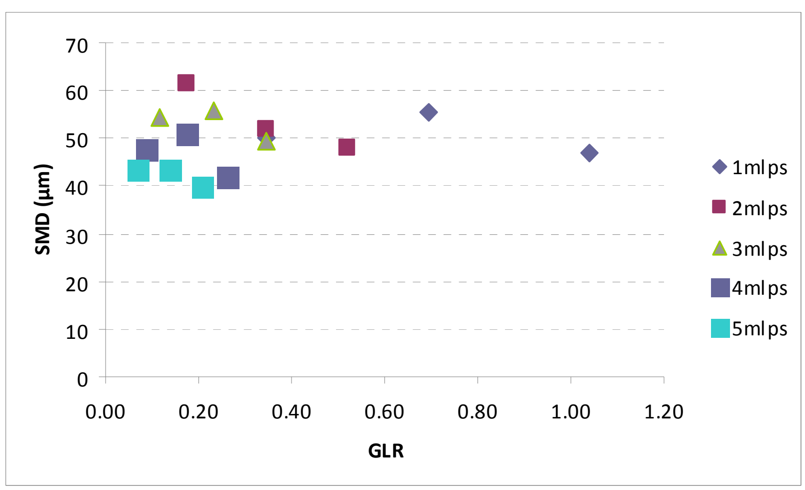


Figure 5. Sauter Mean Diameter (SMD) variation for different liquid flow rates

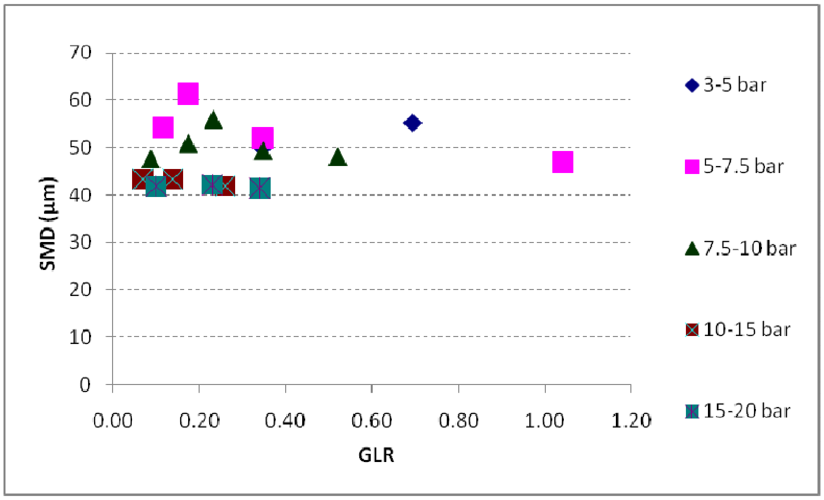


Figure 6. Sauter Mean Diameter (SMD) variation for different pressures

Property	*Values at 25 °C*
Density	917 kg/m^3
Viscosity	32 cP
Surface Tension	34 mN/m

Table 1. Properties of Jatropha curcas oil sample used in the experiments